

What is claimed is:

1. A method for controlling a data flow in a data network, the method comprising:
  - setting a stable integral controller gain  $k_i$  for said data network;
  - specifying a plurality of precedence grades, each of said precedence grades having a priority associated thereto;
  - for each precedence grade, calculating a cumulative data arrival rate  $R(n)$  where  $R(n)$  is the sum of the data arrival rates for a particular precedence grade under consideration plus the data arrival rates of all precedence grades with a higher priority than said particular precedence grade under consideration;
  - for each precedence grade calculating a normalized error signal  $e(n)$ , according to the relation
$$e(n) = (T(n) - R(n))/x,$$
where  $T(n)$  is an assigned precedence grade capacity at time  $n$ , and  $x$  is a nominal packet size;
  - for each precedence grade computing a mark/drop probability  $p(n)$  according to the relation
$$p(n) = \min \{ \max [p(n-1) + k_i \cdot \Delta t \cdot e(n), 0], p_{\max} \}$$
where  $\Delta t$  is the time interval between a  $(n-1)^{\text{th}}$  and the  $n^{\text{th}}$  computation, and  $0 < p_{\max} \leq 1$ ; and
  - for each precedence grade executing a packet mark/drop routine based upon the calculated mark/drop probability  $p(n)$ .
2. The method of claim 1 wherein the number of precedence grades is three.
3. The method of claim 1 wherein the step of setting a stable integral controller gain  $k_i$  for said data network is preceded by the step of pre-calculating a range within which all gains  $k_i$  result in a stable gain.

4. The method of claim 3 wherein the step of pre-calculating a range within which all gains  $k_i$  result in a stable gain for said data network is determined according to the method of:

obtaining for said network a value for said network a set of parameters  $k$ ,  $d_0$ , and  $\tau$ ,

where  $k$  is a steady-state gain of said network,

$d_0$  is a time delay of said network, and

$\tau$  is a time constant of said network;

determining a  $z_1$  in the interval  $\left(0, \frac{\pi}{2}\right)$  satisfying

$$\cot(z_1) = \frac{\tau}{d_0} z_1 \quad ; \text{ and}$$

computing a range of stable gains  $k_i$  for said data network according to

$$-\frac{\tau}{kd_0^2} z_1 \sqrt{z_1^2 + \frac{d_0^2}{\tau^2}} < k_i < 0$$

5. The method of claim 1 wherein the step of for each precedence grade measuring a data arrival rate  $R(n)$  at time  $n$  further comprises:

filtering the data arrival rate  $R(n)$  according to the relation:

$$R'(n) = (1 - \beta) \cdot R'(n-1) + \beta \cdot R(n)$$

where  $\beta$  is a filter gain parameter such that  $0 < \beta < 1$ ,

$R'(n-1)$  is the filtered data arrival rate at time  $n-1$ ,

$R'(n)$  is the desired filtered data arrival rate at time  $n$ , and

$R(n)$  is the cumulative data arrival rate at time  $n$ .

6. The method of claim 1 further comprising a step, preceding the step of for each precedence grade executing a packet mark/drop routine, of:

for each precedence grade testing the cumulative data arrival rate  $R(n)$  against a rate threshold  $T_L$  specific to that precedence grade; and

if the cumulative data arrival rate  $R(n)$  is below or equal to said rate threshold  $T_L$  then bypassing the step of executing a packet mark/drop routine for that precedence grade.

7. The method of claim 1 further comprising a step, preceding the step of for each precedence grade executing a packet mark/drop routine, of:

for each precedence grade testing the cumulative data arrival rate  $R(n)$  against a rate threshold  $T_L$  common to all precedence grades; and

if the cumulative data arrival rate  $R(n)$  is below or equal to said rate threshold  $T_L$  then bypassing the step of executing a packet mark/drop routine for that precedence grade.

8. The method of claim 1 wherein the step of executing a packet mark/drop routine further comprises marking/dropping packets according to a random number generator mark/drop scheme.

9. An apparatus for controlling a data flow in a data network, the apparatus comprising:  
an integral controller having an integral controller gain  $k_i$  setting for which the said network is stable;

a cumulative data rate calculator for calculating a cumulative data arrival rate  $R(n)$  associated with each of said plurality of precedence grades, wherein  $R(n)$  is the sum of the data arrival rates for a particular precedence grade under consideration plus the data arrival rates of all precedence grades with a higher priority than said particular precedence grade under consideration;

an error signal calculator for calculating a normalized error signal  $e(n)$  for each of said plurality of precedence grades according to the relation

$$e(n) = (T(n) - R(n))/x,$$

where  $T(n)$  is an assigned precedence grade capacity at time  $n$ , and  $x$  is a nominal packet size;

a mark/drop probability processor for computing a mark/drop probability  $p(n)$  for each of said plurality of precedence grades according to the relation

$$p(n) = \min \{ \max [p(n-1) + k_i \cdot \Delta t \cdot e(n), 0] , p_{\max} \}$$

where  $\Delta t$  is the time interval between a  $(n-1)^{\text{th}}$  and the  $n^{\text{th}}$  computation, and  $0 < p_{\max} \leq 1$ ; and

a packet mark/drop module for executing a packet mark/drop routine based upon the calculated mark/drop probability  $p(n)$ .

10. The apparatus of claim 9 wherein the number of precedence grades is three.

11. The apparatus of claim 9 wherein the integral controller gain  $k_i$  setting for which the said network is stable is chosen from a pre-calculated range within which all gains  $k_i$  are gains for which said network is stable.

12. The apparatus of claim 11 wherein the pre-calculated range within which all gains  $k_i$  are gains for which said network is stable is determined according to the method of:  
obtaining for said network a value for said network of a set of parameters  $k$ ,  $d_0$ , and  $\tau$ ,  
where  $k$  is a steady-state gain of said network,  
 $d_0$  is a time delay of said network, and  
 $\tau$  is a time constant of said network;

determining a  $z_1$  in the interval  $\left(0, \frac{\pi}{2}\right)$  satisfying

$$\cot(z_1) = \frac{\tau}{d_0} z_1 \quad ; \text{ and}$$

computing a range of stable gains  $k_i$  for said data network according to

$$-\frac{\tau}{kd_0^2} z_1 \sqrt{z_1^2 + \frac{d_0^2}{\tau^2}} < k_i < 0 \quad .$$

13. The apparatus of claim 9 wherein the data arrival rate measurer for measuring data arrival rate  $R(n)$  at time  $n$  further comprises:

a filter for filtering the data arrival rate  $R(n)$  according to the relation:

$$R'(n) = (1 - \beta) \cdot R'(n-1) + \beta \cdot R(n)$$

where  $\beta$  is a filter gain parameter such that  $0 < \beta < 1$ ,

$R'(n-1)$  is the filtered data arrival rate at time  $n-1$ ,

$R'(n)$  is the desired filtered data arrival rate at time  $n$ , and

$R(n)$  is the cumulative data arrival rate at time  $n$ .

14. The apparatus of claim 9 further comprising:

a test module for testing the cumulative data arrival rate  $R(n)$  against a rate threshold  $T_L$  specific to that precedence grade; configured such that

if the cumulative data arrival rate  $R(n)$  is below or equal to said rate threshold  $T_L$  then bypassing the packet mark/drop module for that precedence grade.

15. The apparatus of claim 9 further comprising:

a test module for testing the cumulative data arrival rate  $R(n)$  against a rate threshold  $T_L$  common to all precedence grades; configured such that

if the cumulative data arrival rate  $R(n)$  is below or equal to said rate threshold  $T_L$  then bypassing the packet mark/drop module for that precedence grade.

16. The apparatus of claim 9 wherein the packet mark/drop module further comprises a random number generator drop scheme module.

17. An article of manufacture for controlling a data flow in a data network, the article of manufacture comprising:

at least one processor readable carrier and instructions carried on the at least one carrier; wherein the instructions are configured to be readable from the at least one carrier by at least one processor and thereby cause the at least one processor to operate so as to:

set a stable gain of a integral controller gain  $k_i$  for said data network;  
specify a plurality of precedence grades, each of said precedence grades having a priority associated thereto;  
for each precedence grade calculate a cumulative data arrival rate  $R(n)$  where  $R(n)$  is the sum of the data arrival rates for a particular precedence grade under consideration and the data arrival rates of all precedence grades with a higher priority than said particular precedence grade under consideration;  
for each precedence grade calculate a normalized error signal  $e(n)$ , according to the relation  
$$e(n) = (T(n) - R(n))/x,$$
where  $T(n)$  is an assigned precedence grade capacity at time  $n$ , and  $x$  is a nominal packet size;  
for each precedence grade compute a mark/drop probability  $p(n)$  according to the relation  
$$p(n) = \min \{ \max [p(n-1) + k_i \cdot \Delta t \cdot e(n), 0] , p_{\max} \}$$
where  $\Delta t$  is the time interval between a  $(n-1)^{\text{th}}$  and the  $n^{\text{th}}$  computation, and  $0 < p_{\max} \leq 1$ ; and  
for each precedence grade execute a packet mark/drop routine based upon the calculated mark/drop probability  $p(n)$ .

- 18.A signal embodied in a carrier wave and representing sequences of instructions which, when executed by at least one processor, cause the at least one processor to control a data flow by performing the steps of:
- setting a stable integral controller gain  $k_i$  for said data network;
  - specifying a plurality of precedence grades, each of said precedence grades having a priority associated thereto;
  - for each precedence grade calculating a cumulative data arrival rate  $R(n)$  where  $R(n)$  is the sum of the data arrival rates for a particular precedence grade under consideration and the data arrival rates of all precedence grades with a higher priority than said particular precedence grade under consideration;

for each precedence grade calculating a normalized error signal  $e(n)$ , according to the relation

$$e(n) = (T(n) - R(n))/x,$$

where  $T(n)$  is an assigned precedence grade capacity at time  $n$ , and  $x$  is a nominal packet size;

for each precedence grade computing a mark/drop probability  $p(n)$  according to the relation

$$p(n) = \min \{ \max [p(n-1) + k_i \cdot \Delta t \cdot e(n), 0] , p_{\max} \}$$

where  $\Delta t$  is the time interval between a  $(n-1)^{\text{th}}$  and the  $n^{\text{th}}$  computation, and  $0 < p_{\max} \leq 1$ ; and

for each precedence grade executing a packet mark/drop routine based upon the calculated mark/drop probability  $p(n)$ .